Stream Water Quality and Service Learning in an Introductory Biology Class

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Northland College is a small environmental liberal arts college in northern Wisconsin near Lake Superior. In the fall of 2007 and 2008 students in a mixed science majors/non-majors introductory biology course engaged in a semester-long, service-learning project to monitor E. coli in city stormwater draining into Bay City Creek, a small stream that flows through campus and the town of Ashland before flowing into Lake Superior. Such monitoring is beyond the budget of most municipalities, but is an important public health and aesthetic issue for Ashland and Lake Superior. Our hypothesis was that this service-learning research project would have a positive impact on student learning and student perception of science, and the project would generate useful information for city leaders. Students collected and processed water samples using a standard protocol, analyzed the effect of stormwater on stream water quality, and presented their data in the form of posters to the mayor, a city administrator, and the Provost. Student learning was assessed by a poster-grading rubric, and by online and Northland College instruments. Student perceptions of science were found to be more positive than in the year preceding this project, even when clear answers were not found from their scientific investigation, and there appeared to be no distinction in responses between science majors and non-majors.

INTRODUCTION

Northland College in Ashland, WI is a small four-year liberal arts college with an environmental emphasis. Because of its small size (approximately 600 students), Northland offers a single introductory biology course for science majors and non-majors who take it to fulfill a liberal education science requirement. Typically about a third of entering freshman plan to be science majors, while a third definitely do not. The remaining third are undecided this early in their college career, but are receptive to the STEM (science, technology, engineering, and math) disciplines. One method to make science relevant to both science majors and non-majors is to incorporate into a science course a service-learning component that has clear academic learning objectives, a relevant community or civic engagement project, and a reflective component in which students evaluate the outcome of the project as well as their own learning. Recent studies have shown that service-learning improves student learning and a sense of environmental responsibility because the science becomes relevant (3, 4, 2, 5).

Northland College’s location less than a mile from Lake Superior provides an extraordinary opportunity for students to learn about its watershed and the many complex issues associated with it. Bay City Creek (BCC), a tributary of Lake Superior, is a seven-mile stream that begins in the agricultural land southwest of Ashland, WI, flows through residential areas, four school campuses, including Northland College, before emptying directly into Chequamegon Bay of Lake Superior. While not all students have an interest in biology or environmental issues, all have crossed the two footbridges that span the ravine on campus, and most have walked along the stream and observed the abundant wildlife such as bear, deer, beaver, ducks, and even moose. BCC is a warm water stream that has input from multiple municipal stormwater outfalls (drainage pipes) and frequently has a high sediment load. Consistently high Escherichia coli counts have been found in BCC with sporadic testing, indicating some fecal pollution, but little is known about the dynamics of E. coli levels in the stream, the stormwater, or in Lake Superior. Monitoring stormwater outfalls for fecal pollution and other contaminants is beyond the budget of most communities, including the City of Ashland, but that does not diminish the need for monitoring and determining best management practices, particularly as it applies to stormwater management.

The first goal of our introductory biology course was to introduce freshmen to a scientific investigation of an environmental issue that was of real concern to local city officials and one that had unknown outcomes. This investigation centered on E. coli levels in a single stormwater outfall on campus and its impact on E. coli levels in proximal regions of BCC. A second goal was to involve students in collaborative research groups that would be engaged in a long-term, community-based, service-learning project. A third goal was to enhance science literacy by engaging students in a real-life project that would require research, quantitative analysis, evaluation, and communication. Our hypothesis was that this research project would have a positive impact on student

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learning and student perception of science, as other educators have found with service-learning (3, 4, 5) and would generate useful information for city leaders.

MATERIAL & METHODS

Course design

Concepts in Biology (BIO115) was a mixed majors/non-majors introductory biology course taken primarily by freshmen and taught by two instructors to groups of 24 students each. The course structure consisted of three lectures per week with a two-hour laboratory class, covering a wide variety of topics contained within a one-semester, non-majors textbook. The BCC water quality project was implemented in fall of 2007 and 2008 and, although it was primarily addressed in the laboratory, the project was referred to frequently in lecture, where appropriate. A variety of general biology topics were addressed in the laboratory during the semester; four laboratory exercises focused on the BCC project:

1. Scientific method, experimental design and field testing

During the first week of the course students listened to a presentation by the City of Ashland Environmental Projects Coordinator on stormwater pollution and water quality. One of the city’s unanswered questions was whether the stormwater contributed to fecal pollution in the stream. This environmental topic dovetailed with coverage of scientific method in the lecture. During the first laboratory session, students walked along the stream, were shown potential stream sampling sites, and how to properly collect and process water samples. Students then designed a semester-long project to monitor E. coli levels in a segment of BCC near a single stormwater outfall in order and test the effect of stormwater pollution on stream water quality. With instructor guidance, students considered number and location of sampling sites, experimental control sites, and frequency of sampling. They also considered the practicality and expense of sampling regimes in order to formulate a sampling plan that would be used consistently by all students (see next section). Considering these factors, students in both 2007 and 2008 developed a similar sampling plan: 10 weeks of sampling twice per week, a control site just upstream of the stormwater outfall (site 1), the outfall pipe itself (outfall), the confluence of the outfall and stream (site 2), and two sites downstream of the outfall (sites 3 and 4) (Fig. 1). Students worked in teams of four that were self-selected, although these freshmen students did not know each other or what their majors were prior to the selection.

2. Cell diversity

For another laboratory session, students explored cell diversity and microscopy by viewing a variety of cells from pond water, prepared slides, and a sample of bacteria they had collected from BCC. Students also learned aseptic technique and laboratory safety.

3. Data analysis, statistics, and use of Excel®

Class data collected from BCC were entered by a student teaching assistant into a class database in Excel®. During a laboratory session near the end of the semester, student teams (in most cases the same teams that collected water samples) analyzed the data by Excel®. Student teams were given some guidelines for using Excel® for simple statistics such as mean and standard deviation, and for generating graphs, but teams were free to explore whatever relationships in the data that interested them. Therefore, even though all students used the same data, they chose different aspects to examine and analyze. Due to the complexity of the data and the analysis, students in 2008 analyzed only the 2008 data, even though the 2007 data was available to examine.

4. Scientific reporting and presentation

One laboratory session was devoted to students learning how to use PowerPoint® to develop a poster that followed the format of a scientific report. They also had available to them examples of scientific reporting and posters, including an example of the BCC project from 2007. Students were instructed to address the effect the stormwater outfall had on E. coli levels in BCC and make recommendations to the City of Ashland for reducing pollution. During the final laboratory period of the semester, students presented their posters to fellow students, the Mayor of Ashland (in 2007), the Environmental Projects Coordinator (in 2007 and 2008), and Northland College Provost (in 2008).
BCC long-term monitoring project

Students worked in teams of four to sample stream water at four sites through campus and at the stormwater outfall (Fig. 1). All sites were sampled twice per week for 10 weeks and each group of students had two sampling opportunities. At each site, students took one water sample and also recorded water temperature, turbidity (ranked 0 for clear to 3 for very turbid), stream flow (ranked 0 for no flow to 3 for high flow), and precipitation within the previous 24 hours. During the first laboratory session, students had been shown potential stream sampling sites and how to collect water samples that met state standards (Beach Monitoring Program Requirements, State of Wisconsin Department of Natural Resources); on subsequent sampling days students were supervised by an upper level undergraduate teaching assistant who had taken Microbiology (BIO331) and could answer questions and ensure uniformity of sampling, processing, and recording. Water was collected in clean Nalgene bottles and students followed a standard filtration and culture protocol for water quality monitoring (7) in which 100 ml of water was passed through a 47 mm 0.45 µm filter, and the filters cultured on m-ColiBlue24 (Millipore) broth-saturated pads (in 2007) or on Modified mTEC (Difco) agar (in 2008). Prior to filtering, students diluted water samples 1:10 and 1:100 in sterile 0.9% phosphate buffered saline (physiological saline) in order to achieve countable numbers of bacterial colonies (7). After 24 hours of incubation at the appropriate temperature (37°C for ColiBlue media and 44°C for two hours followed by 35°C for Modified mTEC media), students counted E. coli colony forming units (CFU), and recorded their information on the data sheets. The change in media in 2008 was done because E. coli colonies were visually more distinct on the Modified mTEC media filters and easier to count. In 2008, students in Microbiology (BIO331) did a comparison of the ColiBlue24 and Modified mTEC media and determined that the two methods were equivalent (data not shown).

Assessment

Instructors evaluated student learning from the BCC project by using a grading rubric for student posters and students’ ability to answer questions during the poster session (Table 1). Instructors also noted student attitudes and concerns by listening to student comments during laboratory sessions and on assigned water sampling days.

An online instrument was used to enable students to assess their own learning gains. This instrument was developed by Dr. Elaine Seymour in conjunction with the National Science Foundation-funded initiative called SENCER (Science Education for New Civic Engagements and Responsibilities, http://www.sencer.net/) which promotes service-learning through civic engagement. We utilized this SENCER SALG (6) (Student Assessment of their Learning Gains, http://www.salgsite.org/) instrument in 2006 before the BCC project was implemented, and again in 2007 and 2008 in order to assess change in attitude and understanding of science as a result of the project. Not all of the questions were directly comparable between years because some questions were modified or added in 2008 that more specifically addressed the water sampling project, and the SENCER SALG site itself underwent a revision after 2007. Students received class points for participating in the instrument; the SENCER SALG revealed which students responded but their answers remained anonymous. Nor was it known whether a respondent was a science major or non-major. Sample sizes of respondents were 66 of 123 students in 2006, 47 of 92 in 2007, and 33 of 48 in 2008. Chi square analysis was used to determine significant differences (p = 0.05) for each SALG question of particular interest.

In 2008, students in one section (24 students) of the class taught by one instructor were given the standard Northland College course evaluation to assess student opinions of the instructor and course. This student evaluation was compared to a 2005 course evaluation for the same instructor, before the course implemented the BCC project, and tested for significant differences (p = 0.05). This research has complied with institutional policies on human use.

RESULTS

Stream water quality and stormwater effect on Bay City Creek

When E. coli levels were averaged for each site throughout the sampling period, the highest E. coli levels were in the outfall (Fig. 2), with bacterial levels generally diminishing at sites downstream. Students generally concluded that the outfall did adversely affect stream water quality, although most students failed to note that by site 4, E. coli levels had diminished to levels found at site 1 (the control site) upstream of the outfall. A comparison of data from 2007

![FIGURE 2. Means and standard errors of E. coli CFU/100 ml from all sampling times in 2007 and 2008 at each of 4 sites and a stormwater outfall along Bay City Creek. This figure was generated by the author but is an example of a student team-generated graph.](image-url)
and 2008 further reveals the complexity of stormwater effect because in 2007 the levels at site 3 were actually higher than site 2 at the confluence. *E. coli* levels were significantly higher in 2008 at all stream sites compared to 2007, particularly at the stormwater outfall (Fig. 2). The reason for this increase is not apparent but it was not due to a change in media, as our microbiology students demonstrated.

Students found that there was considerable variation in *E. coli* levels among and within each site for both years (Fig. 3). At all sites *E. coli* levels spiked followed by a quick decline; however, the highest levels were generally at the outfall (dotted line, Fig. 3). One might expect that the amount of precipitation would have an effect on *E. coli* levels in stream water because of fecal material carried into the stream from the watershed and stormwater (1). This effect was not clear for BCC because precipitation differed between 2007 and 2008 in amount and pattern (Fig. 3). The year 2007 was marked by a very wet October following a dry summer whereas, in 2008, there was a large rainfall event in September, with less in October. Total amount of rainfall for September to November was 8.48 inches in 2007 and 7.11 inches in 2008. When rainfall was plotted with *E. coli* levels, students found that in 2007 the peaks in *E. coli* levels followed precipitation patterns (Fig. 3(A)). In 2008, however, there was no apparent correlation of rainfall events with spikes in *E. coli* levels (Fig. 3(B)). The difference in results between 2007 and 2008 make it difficult to make a generalization on the effect of the stormwater outfall on water quality in BCC, but it illustrates the need for more monitoring.

**Assessment**

Students worked effectively in research groups on a long-term monitoring project of *E. coli* in BCC using a standard protocol, and analyzing and presenting their results in a poster. All groups analyzed several parameters of the data and presented them in a variety of ways. They examined patterns in the data, and considered different environmental factors such as rainfall, turbidity, temperature, or location and their effects on *E. coli* levels. All groups modeled their poster after a scientific report and drew conclusions, and almost all groups noted the negative impact of the stormwater outfall on *E. coli* levels in the stream. Greater than 95% of the students were able to individually answer questions about the poster during the poster session, indicating that students had a solid understanding of the environmental issue, whether they were science majors or non-majors. Students seemed enthusiastic in discussing their posters, particularly to the Mayor, indicating that students had a solid understanding of the environmental issue, whether they were science majors or non-majors. Students seemed enthusiastic in discussing their posters, particularly to the Mayor, including one non-major who had early in the semester written a school newspaper editorial about this course, complaining, “I study history. I do not do science.”

SENCER SALG results indicated a consistent increase
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“Doing the Bay City Creek monitoring project made me get a hands-on learning experience. I liked coming up with the results and being able to explain them.”

“Not only has my understanding of the subject changed, I have started to ENJOY learning about science. I find it intrinsically valuable now, which is a plus.”

“I learned that it may take a lot of time, money, and effort and skill to be in the field and sometimes you don’t always get the results you want.”

“I have learned how to better understand data. I now know how to collect it effectively and interpret it correctly. I can recognize when a data point seems out of place, too.”

The Northland College instrument administered in 2005 and 2008 also showed an improvement, but not statistically significant, in student opinions between 2005 (n = 23) and 2008 (n = 18) (Table 2). Due to the nature of the open-ended questions on the assessment form, student written comments were brief and not very informative. For example, to the question “What aspects of this class contributed most to your learning?” typical responses were “Hands on stuff” and “real life applications.”

DISCUSSION

BCC project as service-learning

The BCC project actively involved students in long-term monitoring research on E. coli in a stormwater outfall and a stream flowing through campus, and provided the City of Ashland with valuable baseline data of water quality. The BCC project allowed students to see a direct application of topics covered in lectures, which is one goal of service-learning projects (3, 4, 2). Most students were able to relate to and have interest in some aspect of the project because of the physical proximity of the stream and their common knowledge about fecal pollution and water quality. Service-learning brings relevance to non-majors because they can relate the project to other disciplines (5) and what they see in the news media.

Students designed the study, coordinated the long-term water sampling, and were dependent upon each other to adhere to protocol so that the data was reliable. Students demonstrated responsibility in sampling water and collecting data, and were able to convey the information in a scientific format and a discussion with city officials. Having the Mayor and Environmental Projects Coordinator listen to students

in student assessment scores of the class overall and how various class activities contributed to their learning from 2006 compared to 2007 and 2008 (Table 2). Significant increases occurred in how students thought the structure and activities of the class (including those not directly related to the BCC project) helped their learning, and how science can be used to address complex and real world issues. Interestingly, although students were more confident about doing science as a result of this class, they were not more likely to take additional biology classes.

The 2008 version of SENCER SALG allowed students to write comments for some of the questions. Students took this aspect of the instrument very seriously; their comments were generally very positive and insightful, illustrating that students were confident in investigating a complex science issue. Below are some examples.

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FIGURE 3. Variation in E. coli levels (Log of CFU/100 ml) throughout the sampling season in 2007 (A) and 2008 (B) at 4 sites (solid lines) and a stormwater outfall (dotted line) along Bay City Creek. Data from the outfall show a discontinuous line due to lack of water flow and collection of a water sample on some sampling days. Precipitation (dashed line) that occurred within the previous 24 hours of sampling dates is included in the graph because rainfall is frequently a factor in fecal pollution and may show correlation with E. coli levels. This figure was generated by the author but is an example of a student team-generated graph.
TABLE 2.
Student assessment scores for the SENCER SALG (Student Assessment of their Learning Gains) and Northland College instruments for multiple questions that addressed the class overall, class specific activities, and student confidence and understanding. Numbers represent mean scores, and range from 1 (no help) to 5 (great help). Chi square analysis was used to determine significant differences ($p = 0.05$) in student answers in 2006, before the implementation of the research project, and 2007 and 2008. A significant difference between 2006 and either 2007 or 2008 ($p = 0.05$) is denoted by *, while a significant difference between 2006 and both 2007 and 2008 ($p = 0.05$) is denoted by **.

<table>
<thead>
<tr>
<th>SENCER SALG Assessment Questions</th>
<th>2006 Scores</th>
<th>2007 Scores</th>
<th>2008 Scores</th>
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<tbody>
<tr>
<td>The class overall?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The instructional approach taken in this class **</td>
<td>2.79</td>
<td>3.47</td>
<td>4.0</td>
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<tr>
<td>How the lecture and laboratory topics, activities, reading and assignments fit together *</td>
<td>3.48</td>
<td>3.62</td>
<td>4.2</td>
</tr>
<tr>
<td>The way the course was taught overall *</td>
<td>3.08</td>
<td>3.62</td>
<td>4.10</td>
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<td>How much did each of the following aspects of the class help your learning?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Attending lectures **</td>
<td>3.15</td>
<td>3.72</td>
<td>4.2</td>
</tr>
<tr>
<td>Discussions during class **</td>
<td>2.84</td>
<td>3.52</td>
<td>3.85</td>
</tr>
<tr>
<td>Participating in group work *</td>
<td>3.07</td>
<td>3.29</td>
<td>4.20</td>
</tr>
<tr>
<td>BCC water monitoring research: sample collection, lab work, and data analysis</td>
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<td>3.93</td>
<td>4.20</td>
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<tr>
<td>Your understanding of class content and impact on your attitudes?</td>
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<td></td>
<td></td>
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<tr>
<td>How scientists think about problems</td>
<td>3.61</td>
<td>3.77</td>
<td>3.80</td>
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<tr>
<td>How studying biology helps address real world issues *</td>
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<td>3.77</td>
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<td>Your comfort level in working with complex ideas *</td>
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<td>Your enthusiasm for this field *</td>
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<td>Your interest in taking other biology courses</td>
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<td>Northland College student evaluation – 2005 and 2008</td>
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<td>Course as a whole</td>
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<tr>
<td>Quality of questions or problems raised by instructor</td>
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<td>Amount you learned in the course was</td>
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<td>Relevance and usefulness of course content were</td>
<td>3.4</td>
<td>4.1</td>
<td></td>
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</tbody>
</table>

and read their posters made their science research relevant. Both city officials commented on the expertise, professionalism, and enthusiasm shown by the students. Advanced students in Microbiology also enjoyed their participation in the project. The BCC project therefore was an effective instructional tool, involving higher order thinking – analysis, synthesis, and evaluation of a complex environmental and civic issue.

Students were generally appalled by the high $E. coli$ levels in BCC compared to safe levels for activities such as bathing (< 235 CFU/100 ml)(DNR, Beach Monitoring Program Requirements), but they gained an appreciation for the difficulty in evaluating a complex dataset and making generalizations. After finding the highest levels at the outfall, students felt it was important that the City find ways to manage stormwater pollution. They provided suggestions in the posters, such as requiring that pet owners pick up pet waste. Many communities are faced with high and fluctuating bacterial levels in stormwater, and communities must balance monitoring with best management practices (1). Students learned firsthand how much work was involved in monitoring even a single stormwater outfall. At the end of the BCC project, students provided suggestions for further study: tour the entire BCC watershed to get a “feel for the land,” study an additional outfall as a comparison even if it required more sampling, and sample water in Lake Superior at the mouth of BCC. The latter suggestion indicates that students were making a connection between the research they did on BCC and broader pollution issues.

**Student learning and attitudes**

Students liked the BCC project and the course in general, as evidenced by the student assessment of the course and their positive comments. Since the majority of students in the course were non-science majors or undeclared majors, at least portion of these positive comments came from them, indicating that the BCC project was of interest to a broad range of students. Comments indicated a change in attitude of some students and in their view of complexities of science issues. Students viewed scientific studies more critically, to the point where some students were at times distrustful of other students’ work and quick to look at outlying data as a mistake.

There was an increase in student confidence in doing science, as indicated by a comparison of the SALG instrument in...
2006 to 2007 and 2008. The BCC project allowed students to actually practice science beyond what is performed in a two-hour laboratory session. The improvement of student evaluations of the usefulness of course content from 2005 to 2008 for the same instructor using the Northland College instrument also indicated a positive impact of doing the BCC project. Our “control” group was the 2005/2006 class, before the BCC project was implemented, although it was not strictly a control group because the textbook was updated to a new edition in 2008 and there was a change in one of two instructors. However, the curriculum and structure of the course remained basically the same from 2005/2006 to 2007/2008 except for the implementation of the BCC project.

One goal of the project was to have students provide data that would be useful to city officials and their management of stormwater pollution. The data the students generated prompted the Environmental Projects Coordinator in the summer of 2009 to conduct a survey of E. coli in stormwater catchment basins connected to the stormwater outfall studied in the BCC project. Student data were also used as background information for a grant proposal to monitor E. coli at the mouth of BCC and other stormwater outfalls. This proposal was submitted jointly by Northland College and the City of Ashland in January of 2010 to the USEPA-budgeted Great Lakes Restoration Initiative.

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REFERENCES